E4 Bug Off Team Project: Mitigating Japanese Beetle Damage

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Abstract

Our client Tanja Srebotnjak wants to mitigate the damage that Japanese Beetles have caused to plants in the Williams College Community Garden. The Japanese Beetles have heavily damaged plant leaves, depleting the plants of nutrients and creating an appealing look on the leaves. In this project, the E4 Bug Off Team helped Tanja solve this problem by designing a durable, easily operable, and human and bee friendly device that would repel the Japanese Beetles from the damaged plants by dispersing unappealing scents.

Initially, our client Tanja, and Mike Evans, the Assistant Director of the Williams College Community Garden, expressed several desires and constraints when it came to creating a design, and expressed interest in two methods of beetle mitigation: either by keeping the beetles out of the plots altogether or by removing them off the leaves. They also highlighted several needs that our design needed to fulfill, such as durability to the elements and sustainability, and with this information we were able to create a list of objectives, constraints, and functions. We then prioritized and ranked each one using a Pairwise Comparison Chart, and with this information, we brainstormed designs. We made a Best of Class Chart and from these design alternatives, Tanja and Mike expressed that they were most interested in using scents to repel the Japanese Beetles.

After creating our first low resolution prototype using materials in the design studio, and receiving feedback from Tanja and Mike, Professor Tsai, and the class, we designed our next iterations with CAD models, then started building our final prototype using 3D printing, Blue Tack(mounting putty), superglue, reed diffuser wicks, fishing line, and hard plastic. The biggest challenge we encountered was testing, since we nor Tanja had access to Japanese Beetles. After considering several options, we decided to focus on measuring how well the scent is dispersed in area coverage, how easy the device is to operate, how maintainable the device is, and how durable or sustainable the device is, rather than measuring how well the Japanese Beetles were removed since it was impossible to test it.

The evaluation testing highlighted several surprising outcomes of our design. Employing human participants, we learned that the 1 oz of the peppermint oil concoction we tested with was very easily dispersed and quite pungent, and would be long lasting and strong enough to repel Japanese Beetles without replacement for several days. The results of the drop and rain tests indicated that our device is durable enough to thrive in the oftentimes heavy winds and rains of the East Coast without significant damage. We also tested the operability and versatility of the device, which demonstrated that the student interns at Williams College would be easily able to install the device onto the different trees. These tests underscored the successes of our device, while also bringing light to aspects that could be improved upon for future iterations. This report summarizes our findings.

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Introduction

Tanja Sebotnjak is a former Harvey Mudd E4 professor and currently the Director of the Zilkha Center for Environmental Initiatives. Passionate about sustainability, she is interested in finding long-lasting and environmentally friendly solutions to real world issues, in her work, and research. In charge of the Williams College Community Garden, she and Assistant Director Mike Evans are looking for a solution that would mitigate the Japanese beetle damage on their plants.

Japanese beetles are an invasive species and extremely harmful pests that chew grass roots and skeletonize plant leaves, depleting plants of nutrient absorption. Japanese beetles are only active in the East Coast during the summer months of late May to July, as the winter frost prevents them from breeding and proliferating and are approximately ⅓ to ½ an inch long, making them difficult to remove by hand. In the past, Tanja and Mike have employed student volunteers to hand pick the beetles off the plants, but with their small size, the process is difficult and inefficient, and thus they are looking for an alternative solution to eradicate these pests. The primary method of attack that the Japanese beetles employ on the Community Garden is through skeletonizing plant leaves of the raspberry, purple flowering raspberry, quince, apple, and grape plants. There are several more sustainable, already existing methods that Tanja and Mike had researched: using soapy water, pheromone traps, or netting, but these designs require high maintenance, have been employed at the Community Garden previously, or obstruct bee activity, which is important for pollination. After several meetings with Tanja and Mike, consulting a garden expert at the Armstrong Garden Center, combined with research, we learned that there are several scents that repel Japanese beetles: wintergreen, neem, chives, peppermint oil, and garlic, which would be a more eco-friendly alternative to the already existing methods.

Revised Problem Statement

We want to design a solution that will mitigate Japanese beetle leaf damage to raspberry, purple flowering raspberry, quince, apple, and grape plants in the East Coast without using pesticides, or anything else that may harm non-invasive insects, humans, or animals. The solution should also be relatively inexpensive, easy to install, and allow for physical work in the garden to proceed unhindered. Optionally, the solution would also keep woodchucks from getting berries without harming them.

Constraints

1) *No methods, pesticides, or chemicals(such as pyrethroids) that can harm humans*: Aligns with Tanja and The Williams College Community Garden's value of sustainability, maintaining soil health, and human health. Pesticide use on plants has been linked to the depletion of plant and soil nutrients, as well as cancer and other diseases in humans. Many families, faculty, students, and young children visit the garden and thus, it is crucial for the garden to be safe for humans. This falls under the category of constraint, as if we use any methods that can harm humans, the design fails.
2) *Under budget ($150 [+$50]):* The Engineering Department has allocated an equal amount of monetary resources for all teams to use, and we should respect this budget. We either are over the budget or under, so this counts as a constraint for our design.
3) *No chemicals, solutions, or methods that can harm woodchucks or bees:* Bees and woodchucks are essential to the wellbeing of the garden and the symbiotic relationships of the habitat. Bees are the primary pollinators of the plants and thus, any method we employ to mitigate the Japanese beetles must not mitigate them either. Similarly to the first constraint, this is evaluated in a binary fashion; either we use methods that can harm woodchucks or bees or not, so this is a constraint.

Objectives

1) *Mitigates beetle damage to plants:* This is our primary objective for our design, as it's our client's main concern. Although the wording takes the form of a function, it is classified as an objective, as the verb is not a concrete action but instead describes the efficiency of our design. Our final design solution considers this objective through emission of scents that Japanese beetles stay away from. If the beetles are repelled by the scent, then the plants will not be damaged by them.
2) *Works with multiple different plants:* Our client has many different plants in their garden, such as raspberry, purple flowering raspberry, quince, apple, and grape plant. Our solution aims to work with all these different plants. This is an objective as the types of plants that the design works with may vary beyond a binary evaluation. The final design solution meets this objective with its hanging mechanism, which is a simple loop of fishing line that can be hung on branches or wooden stakes, and its light weight.
3) *Durable to the elements*: With hot and humid summers in the East Coast accompanied with frequent rain, our device should be able to accommodate diverse weather conditions. This objective and the subsequent objectives follow the standard adjective description. Here, we want a durable design. The final design solution is primarily composed of plastics that are very comfortable in the conditions mentioned above.
4) *Long-lasting:* Our client wishes to use the solution over a long period of time to help save costs in the long term. Long-lasting is an objective here as it is a measurable characteristic of the design. Our final design solution takes long-lasting into consideration by using long-lasting plastic, which ties into durability to the elements.

5) *Easy to remove:* Our client also only needs the solution in the summer when the beetles are active, so it would be best if it can easily be uninstalled when not needed. Feasibility is a measurable characteristic and so this is an objective for our design. Our final design solution's simple hanging mechanism and small size allows easy removal of the design.
6) *Easy to maintain:* Student workers tend the garden, so it would be better for our client if our solution was easy to maintain. The client also mentioned that they would not like to have our design require more than an hour of labor per week. The final design solution reflects this with the long lifetime of peppermint oil in a reed diffuser, which lasts a month on average with around 3 oz. of oil. Just as the previous objective, feasibility is measurable, and so being easy to maintain is an objective for our design.
7) *Affordable:* It would be ideal for our design to be put on all the plants that have suffered Japanese beetle damage and thus our design must be able to be built and installed multiple times. Therefore, having an affordable solution will allow production of multiple products to be cheap. The measurability of cost makes affordable an objective for our design. Our final design solution mainly utilizes 3D printing, which will be cheap for mass production. The other supplies to build our final design solution are cheap for large quantities, especially peppermint oil in bulk.
8) *Safe:* Many families, faculty, and students frequent the Community Garden, and thus the design must not have any sharp parts that could injure people. This is separate from the chemicals and pesticides constraint, and is instead a measurable characteristic of the shape of the design, making it an objective. Our final design solution answers this by being light weight and having no sharp points to it.

Prioritization of Objectives (PCC)

	Affordable	Easy to maintain	Works with different plants	Durable to the elements	Long-lasting	Easy to remove	Mitigates beetle damage to plants	Safe	Total
Affordable	X	0	0	0	0	0	0	0	0
Easy to maintain	1	X	1	1	1	1	0	0	5
Works with different plants	1	0	X	0	0	1	0	0	2
Durable to the elements	1	0	1	X	1	1	0	0	4
Long-lasting	1	0	1	0	X	1	0	0	3
Easy to remove	1	0	0	0	0	X	0	0	1
Mitigates beetle damage to plants	1	1	1	1	1	1	X	1	7
Safe	1	1	1	1	1	1	0	X	6

Figure 1: Pairwise Comparison Chart ranking the objectives

Based on the PCC, the order of importance for our objectives is:

1. Mitigates beetle damage to plants
2. Safe
3. Easy to maintain
4. Durable to elements
5. Long-lasting
6. Works with different plants
7. Easy to remove
8. Affordable

We put mitigates beetle damage as our top objective as it's what our client is most concerned with and the main purpose of our device. Safety was made second as our client always stressed how important it was for our solution to be safe in all our meetings since it was likely that children would be near the solution. We made easy to maintain our third concern as our client told us that the solution should not require too much human attention or labor, like about an hour of labor a week, though they did not stress it as much as safety. Durable to elements was next as although important, the weather in the East Coast around the summer wasn't too harsh. Long-lasting followed, as although our client stressed that they wanted a long-lasting solution, we felt that the objectives we stated earlier were more important since if we'd rather meet one of the other objectives or long-lasting, we would always choose one of the earlier stated objectives since they led to a more functional solution. Next was working with different plants as we as a team felt it would be a rather easy objective to meet, so we weren't too concerned about it. Easy to remove followed, as our client said it would be fine if they had to leave the solution out all year, but that they'd rather not if possible. Finally we made affordable our least important objective as our client stressed to us that it was fine if we went a bit over budget, showing it wasn't that big of a concern for them.

Functions & Morphological Chart

After the second client meeting with Tanja and Mike, combined with research, we were able to come up with a list of functions and means for our design.

1) Keeps beetles out from garden plots
2) Take beetles off of the plants regularly
3) Kill beetles
4) Quarantines beetles
5) Prevents beetles from eating the leaves
6) Removes as many Japanese beetles as possible
7) Keeps woodchucks from berries (stretch goal)

As the first four functions fall under function 5 and 6, and function 7 is a stretch goal, we omitted the three from our morphological chart.

Function	**Means**								
Keeps beetles out from garden plots	device surrounds the exterior or circumference of plot	Wire netting	Luring traps outside of the plots	Chemical scent barrier?	Beetle recognition lasers >:D	Repulsive sound waves	Surround with plants that are less appealing to the beetles	
Take beetles off of the plants regularly	Picking robot	Human labor (not viable)	Device operated by hand to pick beetles	Plant-shaking device + beetle collection	Nozzle or spray to distribute soapy water/insecticide	Leaf scrapers/ rakes?	Vacuum	
Kill beetles	Soapy water	Traps	Non-harmful chemicals/insecticides	Predator pest (tachinid)	Predator animals (birds)	Milky spore disease	Neem oil	destroy beetle hives
Quarantines beetles	Containers that holds caught beetles	One-way entry trap	Wet and slippery containers	Special geometries that prevents climbing				

Figure 2: Morphological Chart

Design Alternatives

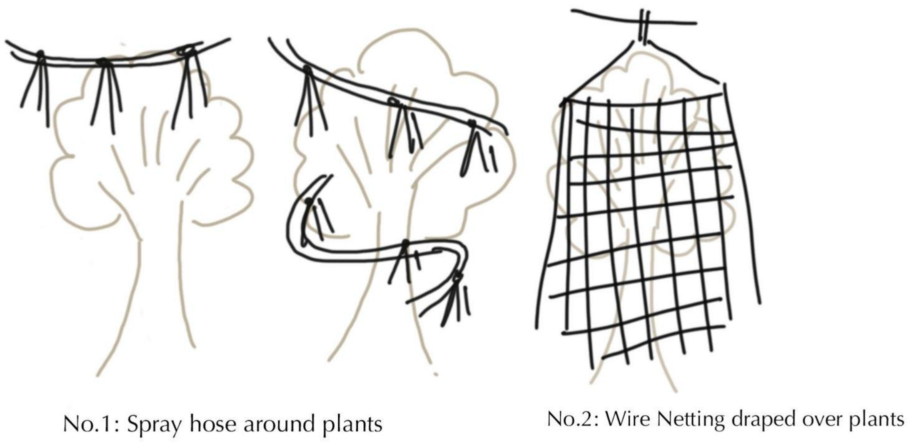

Figure 3: Our first two design alternatives

We created two initial designs that fit the objects, functions, and constraints that Tanja and Mike had expressed, which are drawn above.

1) Spray hose contraption around plants, dispersing repelling scents
2) Wire netting draped over plants

We came up with the first design alternative as we did research and found that there were scents Japanese beetles didn't like and avoided.[1] This was later reinforced when our client Tanja told us that her chives were unharmed by the beetles, which emitted a scent they didn't like. We came up with the second design alternative as it seemed like an easy way to keep the Japanese beetles out of the plants without needing pesticides. With this information, we noticed that we could also cover the wire netting with the repelling scents to help dispel the beetles or sticky material to quarantine them onto the wire. We also came up with the following design alternatives:

3) Strong currents/fans that push beetles away from chosen plants
4) Scent Dispenser

We came up with the third design alternative as we were told by Mike it takes little force to remove the Japanese beetles from the plant, so it seemed feasible that we could use strong currents from a fan to push the beetles away from the chosen plants and even blow them off the plant. Finally, the fourth design alternative followed the same logic as the first design alternative as it used repelling scents to keep beetles out of the garden, but instead the scents were emitted from a small device near the plant.

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[1]Source: https://pestpointers.com/scents-that-japanese-beetles-hate-and-how-to-use-them/

Selection Among Alternatives

With these four design alternatives in mind, we created a best in class chart, shown below.

Best of Class Chart				
Designs	**Design 1: Spray hose contraption around plants, dispersing repelling scents**	**Design 2: Wire netting draped over plants**	**Design 3: Strong currents/fans that push beetles away from chosen plants**	**Design 4: Scent Dispenser**
Constraint 1: No pesticides or chemicals that can harm humans	X	X	X	X
Constraint 2: Costs under $200	X	X	X	X
Constraint 3: No solutions that harms bees or woodchucks	X	FAIL	FAIL	X
Objective 1: Mitigates beetle damage	3	1	4	2
Objective 2: Safe	3	2	4	1
Objective 3: Easy to Maintain	3	2	4	1
Objective 4: Durable to the elements:	3	1	4	2

Figure 4: Best of Class (BOC) Chart

We can immediately get rid of the second and third designs as they violate the constraint of not harming bees or woodchucks. The wire netting of the second design violated this constraint as we wrongfully assumed that the bees were smaller than the beetles, as the bees were actually larger. Therefore the second design would not allow bees into the desired plants, which Tanja expressed was important because of the bees' role in pollination in the garden. The strong air currents of the third design violate the constraint of not harming the bees, as the bees would be affected by the strong currents/fans that push the beetles away from the plants that require pollination. Thus we were left with the first and fourth designs. Looking at the BOC Chart, we can see that the fourth design outscored the first design on all the objectives. The first design would also not be very aesthetically pleasing, difficult to install, and more costly and less environmentally friendly due to its size and materials, things that don't apply to the fourth design or occur to a lesser extent. In conclusion, after presenting our design alternatives to our clients, Professor Tsai, and Professor Santana, and judging them with a BOC chart, we chose to combine the concepts of using scents to repel the Japanese beetles and a mechanism that would disperse the scent, which was our fourth design.

Final Prototype Design: Functions and Means

Figure 5.1: E4 Team Final Prototype,"Bye Beetles"

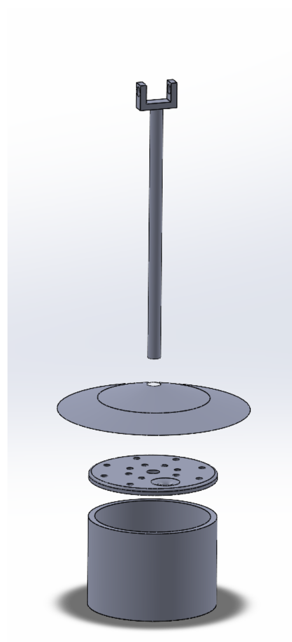


Figure 5.2: E4 Team Final Prototype CAD Demonstration in exploded view (Rod, conical hood, vessel's lid, and vessel from top to bottom)

Our design consists of 4 main components: vessel with holes, conical hood, rod, and reed diffuser wicks. The vessel contains the scent and holds the reed diffuser sticks and rod in place. The conical hood shields from rain and protects the reeds, and is adjustable since it is held in place with removable mounting putty. The rod attaches the vessel to the tree, and has a clear fishing line that is adjustable for different plants. Lastly, the reed diffusers are porous and absorbent, and affordable and easy to find at most home decor stores. Another important aspect we would like to highlight is that we moved from a drip mechanism, from our low resolution prototype, to a reed diffuser design for our final prototype. This new design is easier to maintain and more efficient as it would better disperse the scent with minimal hand operation. Furthermore, wooden reeds are more durable to the elements and longer lasting than flimsy watercolor paper, which fits with our objectives of durability and environmentally friendly.

Although 3D printing filament is not the most environmentally conscious material, our client does not have access to a machine shop, but does have 3D printing resources. However, the scent and diffuser sticks create minimal single-use waste, and thus, these materials are better for the environment. Thus, we decided that 3D printing would be the most feasible method for our client to replicate the vessel and rod parts. These components work together to create a design that deter Japanese beetles while being durable, easy to operate, feasible and accessible for the client to recreate, and as environmentally friendly as possible.

The functions of our design and the means by which they were achieved are below. Note that we added new functions that were more relevant to our design and removed functions that were irrelevant to our design.

1) *Keeps beetles out from garden plots:* We accomplished this through the means of employing reed diffuser wicks and arranging them in a circular pattern on the lid of the device. The reed diffuser disperses the scent so that the Japanese beetles avoid the plants.
2) *Fits on different plants:* We accomplished this function through the means of using clear, durable fishing line. The fishing line is adjustable and easily removable, allowing it to fit on different plants.
3) *Prevents beetles from eating the leaves:* Because the beetles will not enter the garden plots because of the scent, they will not be able to reach the plants' leaves, as well as breed and lay eggs in the vicinity in the tree.
4) *Removes as many japanese beetles as possible:* From our testing, we learned that the positioning of our reeds and the 1 oz peppermint oil concoction allowed for the scent to be dispersed past 5 yards. Since it reaches this broad distance, it will deter as many Japanese beetles in the vicinity as possible.

Evaluation of Design

When evaluating our design, we came up with five questions we wanted our design to answer:

1. How easily maintained is our design?

Our client Tanja expressed that easy maintenance is one of the most important objectives, as she would prefer to spend less than one hour per week actively operating the device. Leaving the prototype filled with peppermint oil and qualitatively measuring how long the scent lasts will demonstrate how frequently the scent must be replaced and thus how easy it is to maintain.

2. How well is the scent dispersed?

Our primary objective is to mitigate beetle damage, and so we wish to see how far the peppermint scent disperses through the air and how strong the scent would be, as those factors correlate with more effective repulsion for the Japanese beetles. By qualitatively testing the strength of the scent and quantitatively recording how far the scent goes, we can see how well the scent is dispersed.

3. How durable is the device to the environment?

This question pairs with the objective of durability to the elements. In the summer, Williams College experiences frequent rain and windy periods. Testing our prototype in different conditions will give us a picture of how durable the design will be in the East Coast.

4. How easy is the device to operate?

This question pairs with the objective of easy to maintain and easy to remove. Easy operation allows for easier maintenance and since the device is only needed in the summertime, the device should be easy to remove when the weather is cooler. Furthermore, many students volunteer at the student garden so the device should be easy to operate for those that are less experienced with garden work and engineering. For our final prototype design, we are still using a thread or strap to easily secure our device on branches or hooked stakes.

5. How well does the device work with multiple different plants?

The Japanese beetles in the Williams College Community Garden attack raspberry, purple flowering raspberry, quince, apple, and grape plants, which are of varying sizes and shapes. By considering the individual differences between each plant, we realized that we needed to craft a design with an easily adjustable attachment method or shape. For our final prototype, we believe it to be easily hung on trees and for bushes it will likely need a hooked stake.

With these five questions in mind we came up with metrics to evaluate how well our prototype answered our desired questions. This evaluation plan and the results from it are below.

Question 1: How easily maintained is our design?

Evaluation: Time how long it takes for the scent to be no longer present and require more reeds and oil to be operational.

Description	Score
It takes more than a week for it for it be replaced	5
It takes more than 5 days for it to be replaced	4
It takes more than 3 days for it to be replaced	3
It takes more than a day for it to be replaced	2
It takes less than a day for them to be replaced	1

Figure 6.1: Metrics for testing how long the scent lasts

Justification: Our design should be as long lasting so it needs to be replaced less often and thus takes less maintenance.

Results: While we didn't have enough time to properly test our design, based on the amount of oil we used on the night of testing and other people's findings on how long the scent lasts, it's likely that our device would not need to be replaced/maintained for several days at the least.[2][3] Even then, replacing the oil and reeds would not take long. It is also likely that increasing the amount of oil in the device would increase the time between maintenance periods.

Question 2: How well is the scent dispersed?

Evaluation: See how far away participants can get from the design and still be able to detect the scent.

Description	Score
Scent detected over 4 yards	5
Scent detected over 3 yards	4
Scent detected over 2 yards	3
Scent detected over 1 yards	2

[2] Source: https://oliverandgrapely.com/how-long-do-essential-oils-last-how-to-store-for-best-shelf-life/
[3] Source: https://www.featherandblack.com/online-features/inspiration/how-to-use-a-reed-diffuser

Scent detected under 1 yards	1

Figure 6.2: Metrics for testing how well the scent is dispersed

Justification: After talking with Professor Santana, Professor Tsai, and Tanja, we decided that the most feasible method was to employ human subjects to measure the efficacy of the scent.

Results:

Participant Number	Participant	Score	Feedback
1	ES	3	He could start to smell the scent at 5 feet but felt the feeling of it at 5 yards
2	JP	5	felt a very slight burning sensation in nostrils
3	LC	3	Burns nostrils
4	BD	5	Easy to smell
5	AT	2	She thought the purpose was to suppress the smell
6	JN	4	He did not know what it was supposed to do
7	JL	5	She could smell the scent right away at 5 yards
8	MB	5	Smelled it entering the E4 studio

Figure 7.1: Scores and feedback for each participant for evaluating scent dispersion

The scent was detectable from a decent distance by humans. Looking at the data, we see an average score of 4, showing that our design does a good job of dispersing the scent. After some more time had passed, the scent spread and was detectable from an even larger range, as people could smell just by entering the E4 studio. The amount of scent emitted could also be improved by using a different mixture of oil, water, and alcohol to help promote the scent's dispersion, as we only estimated the quantities needed. Due to both of these concerns we'd like to do further tests as it's range may be larger than what we got from this test. Although it is unknown how strong the Japanese beetles' sense of smell is, our device would likely do a decent job as Japanese beetles have a greater sense of smell than humans[4].

Question 3: How durable is our device to damage from the environment?

Evaluation 1:Test to see how the device is damaged by strong wind (can do this with fans)

Description	Score
Device is in the same condition	5
Device has minimal damage, such as scratches	4
Device is moderately damaged (not exceeding dents)	3
Device is operational but in bad condition	2
Device is unoperational	1

Figure 6.3: Metrics for testing how durable the device is to strong wind

Justification 1: Human observation of physical damage is the most efficient and feasible method to detect the durability of our device.

Results 1:

RPM of Fan	Score	Feedback
300	5	A little bit of wobble but no damage
350	5	Good
380	5	Good
390	5	Good
Parsons Hallway near	5	A little bit of wobble but no damage

[4] Source: https://www.tribtoday.com/life/lifecovers/2021/04/qa-how-do-i-get-rid-of-japanese-beetle-grubs/

courtyard at 8pm		
Parsons Courtyard at 8pm	5	Good

Figure 7.2: Results for wind simulation

Winds of moderate velocity did not visibly damage our device. The device wobbled a small amount in changing wind, but not enough to fall if placed securely on its branch/hanger. No liquid was lost as well. Overall our prototype got a score of 5 for this test, showing it to be durable to wind.

Evaluation 2: Drop the device from a reasonable height and see how it's affected

Description	Score
Device is in the same condition	5
Device has minimal damage, such as scratches	4
Device is moderately damaged (not exceeding dents)	3
Device is operational but in bad condition	2
Device cannot be operated	1

Figure 6.4: Metrics for testing how durable the device is to height drops

Justification 2: Human observation of physical damage is the most efficient and feasible method to detect the durability of our device.

Results 2:

Pressure Level of Shower Water	Condition	Score
Level 1	Very Good	5
Level 2	Very Good	5
Level 3	Very Good	5

Figure 7.3: Results for rain simulation

Varying levels of water, from a simulated drizzle to a downpour, did not visibly damage our device. The cover did its job well. A small amount of water gathered on the sides and top of the device. A very small amount of water made it into the chamber with the scented oil, but did not affect the strength of the scent as water was already an ingredient for the scent. Overall our prototype got a score of 5 for this test, showing it to be durable to rain.

Evaluation 3: Test to see how the device is affected by rain simulated with a shower head.

Description	Score
Device is in the same condition and operational in rain	5
Device is operational in the rain but slightly damaged	4
Device is operational in rain but moderately damaged (not exceeding dents)	3
Device is unoperational in rain but operates after rain is no longer present	2
Device is fully unoperational, even after rain is no longer present	1

Figure 6.5: Metrics for testing resistance to rain

Justification 3: Human observation for physical damage is the most efficient and feasible method to measure the durability of our device.

Results 3:

Drop Height	Surface Dropped Upon	Condition	Score
6 feet	Soil	Very Good	5
6 feet	Concrete	Top part fell off due to the detaching of the rod and the base, but easily repairable with more superglue. The lid is cracked but	3

		was easily fixed with more tape	

Figure 7.4: Results for drop test

Drops from a moderate device will not destroy our device. A drop onto a soft surface, such as soil, will inflict little to no damage to our device. A drop onto a hard surface, such as concrete, may break the connection between some of our parts, but will likely be easy to repair, as well as damage the cone. This could also be resolved by changing how the parts of the device are connected. Currently the rod is attached to the box with superglue, but the device would likely be more durable to be dropped if it was connected some other way, such as a tapped hole or instead attaching the lid to the body with grooves. The cone could also be made more durable as it's currently made from a thin piece of plastic used to make a folder, which could be improved with a thicker piece of plastic.

Question 4: How easy is the device to operate?

Evaluation: Have participants hang the device, making sure to time them and asking for feedback.

Description	Score
Takes under 30 seconds to hang	5
Takes under a minutes to hang	4
Takes under 2 minute to hang	3
Takes under 3 minute to hang	2
Takes more than 3 minutes to hang	1

Figure 6.6: Metrics for testing operability

Justification: Employing liberal arts students as participants is representative of the students at Williams College that would use the device after our client creates it.

Results:

Participant number	Participant	Time to Hang	Score (1-5)	Feedback
1	CS	34 seconds	4	Easy to set up, looks nice, does not understand it's function

2	LB	32 seconds	4	N/A
3	JC	43 seconds	4	Dropped it
4	DL	33 seconds	4	Had concerns that the cone should be insoluble and thought the box may melt as it's petroleum-based
5	NE	32 seconds	4	N/A
6	WM	34 seconds	4	N/A
7	PG	2 minutes 14 seconds	2	Dropped it, Found the fishing wire hard to knot

Figure 7.5: Results for participants' times it takes to operate

Our device is fairly simple to set up. However, overall it got a score of 3.7, showing that there is still room for improvement. The hardest part of the process seemed to be tying the knot in the fishing line. Admittedly, though the fishing line is durable, it is hard to tie. Alternatives that are similarly strong but easier to tie likely exist and might work better for our design. We could also use an adjustable strap with a locking mechanism that's already attached to the device, requiring only to be adjusted for the specific plant and locked, no tying needed.

Question 5: How well does it work with multiple different plants (trees, bushes, etc.)?

Evaluation: Have participants assemble and hang the device on different plants

Description	Score
Works with all plants, no stakes requires	5
Works with all plants, stakes required for some or all plants	4
	3
	2
Does not work with any plants, even if stakes used	1

Figure 7.6: Metrics for measuring versatility with different plants

Justification: The Japanese beetles attack raspberry, purple flowering raspberry, quince, apple, and grape plants in the Williams College Community Garden, thus it is important for the design to work with multiple different plants.

Results: Our team members hung it on a variety of different plants and trees around campus. The device hung without damaging itself or the plant, and at worst weighed a branch down about a foot lower than its original height. We also tested it on coat hangers, door handles, and other stake-like objects to help emulate hooked stakes. Again, there was no damage to the hangers or the device. In fact, when hung on a door handle, it did not weigh the handle down enough to open the door. The design definitely deserves a score of 5 on plants with branches and a 4 on those without bushes as it could be hung from a nearby hooked stake. We had some difficulties with pushing an already tied string onto a branch with foliage, but this issue would be easily solved by tying the device onto the branch directly.

Impact of Design

Based on our research and tests, our design will help mitigate the damage done by the summer Japanese beetles on the Williams College Community Garden by emitting unappealing scents. Furthermore, our design can be a piece that our client could proudly display to the families, faculty, and students that frequent and enjoy the Community Garden, acting as an educational demonstration in an easily accessible, real-world context. In the garden, the hanging device illustrates how they can remove harmful pests like Japanese beetles, while not affecting beneficial pollinators, such as bees.

Our design and these findings are important because there are not many solutions to Japanese beetle damage in the industry that do not require chemical pesticides, intensive human labor, and harm to beneficial pollinators. In contrast, our design examines a method that does not exist in the industry yet; our design employs sustainable, biodegradable scents that are dispersed in a durable container that requires minimal human labor, while being versatile to many different plants.

Looking at the larger picture, if the industry could adopt a similar, more sustainable and efficient alternative to traditionally harmful pesticides, there could be a greater shift towards working against products that create long-lasting detrimental effects on the environment and people. Many pesticides that have been directly associated with the non-renewable depletion of soil nutrients, as well as critical health issues.

Future Recommendations

After thoroughly testing our design, we can conclude that our design can be improved in several different aspects. Our device could be made more accessible by hanging the device with an adjustable strap that has a locking mechanism in case of rampant weather conditions, as the rod of our design did come off when we performed a drop test at a height of 6 feet upon concrete.

Furthermore, our device could be made more durable by using a thicker piece of flexible plastic, such as shapeable plexiglass, for the conical hood. Another aspect that could be improved upon is by connecting the lid to the box with grooves instead of the rod to the box with superglue for greater durability. Finally, we could also improve the dispersion of scent by creating a better researched solution of oil, water, and alcohol for the reed to absorb, perhaps by consulting a licensed entomologist or chemist specializing in bugs or Japanese beetles. With further improvements to our design, our client would require less devices to cover their full garden, which would be easier to hang, more durable to the environment, and easier to operate, and perhaps, other community gardens in the East Coast could use our design for their own specific pest issues.

Final Design CAD (Pack & Go)

Our Final Design CAD (Pack & Go) is located here.

Part Drawings

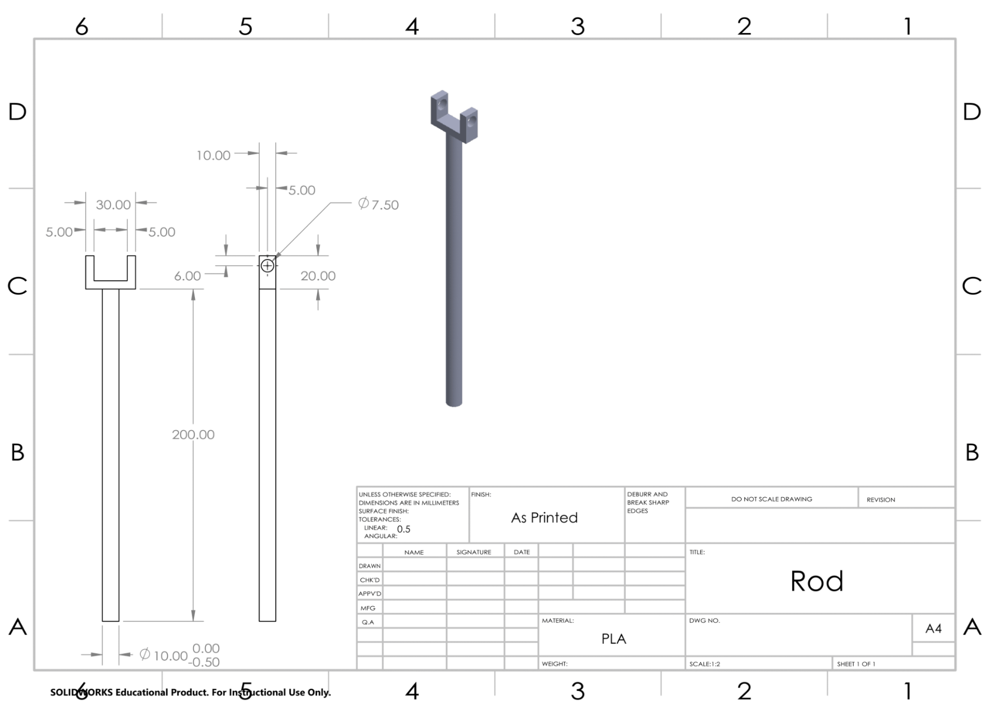


Figure 8.1. Drawing of Rod

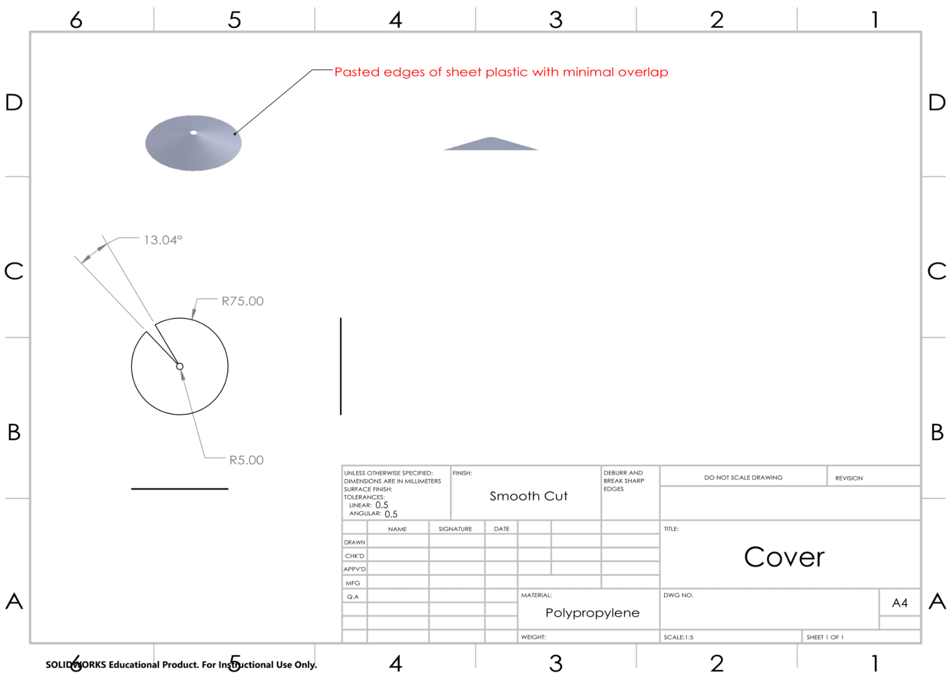


Figure 8.2. Drawing of Conical Hood

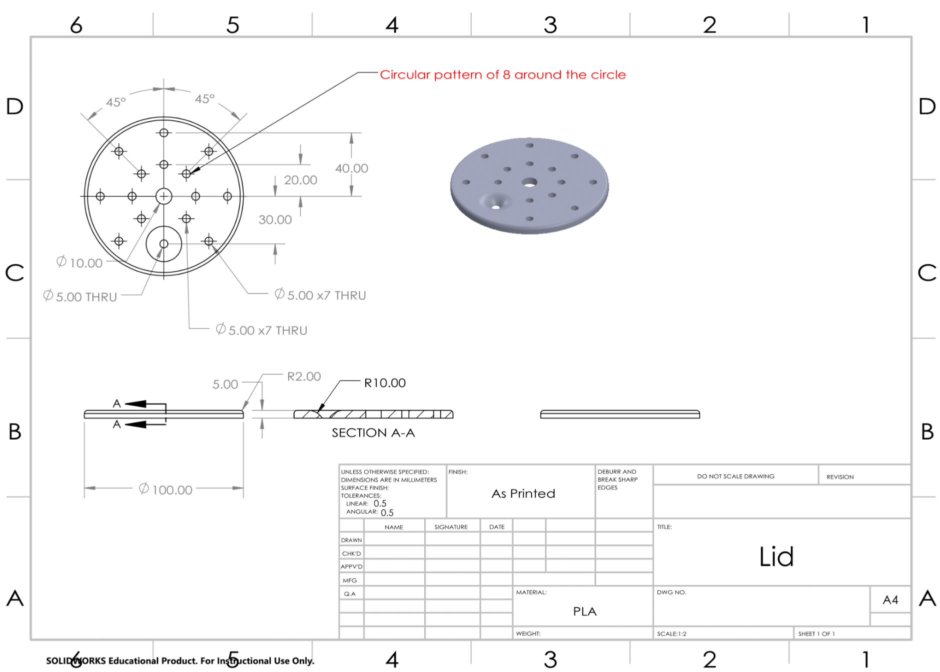


Figure 8.3. Drawing of Vessel Lid

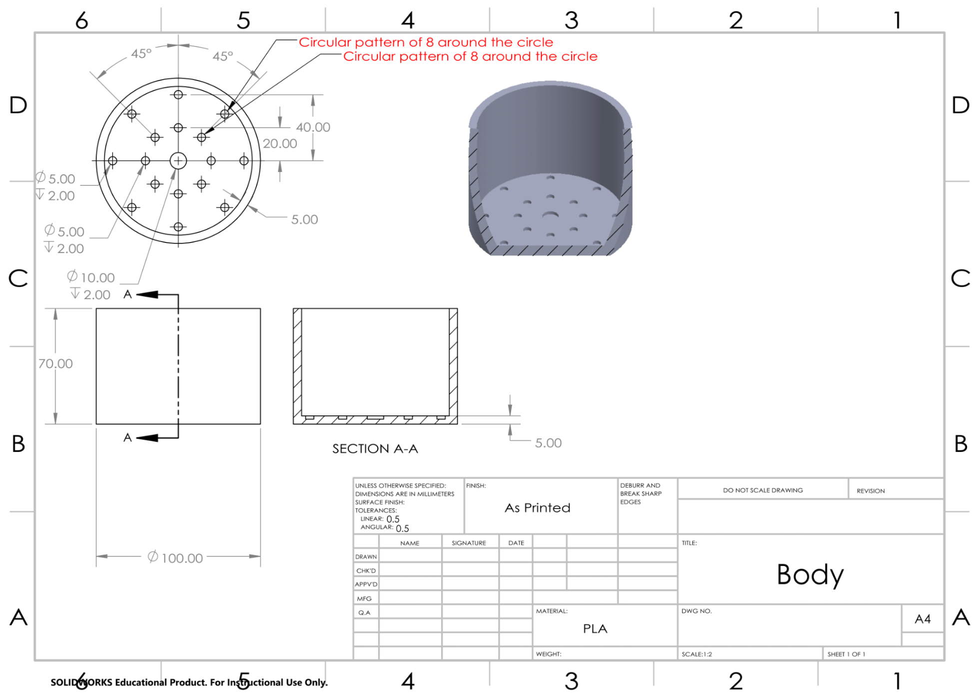
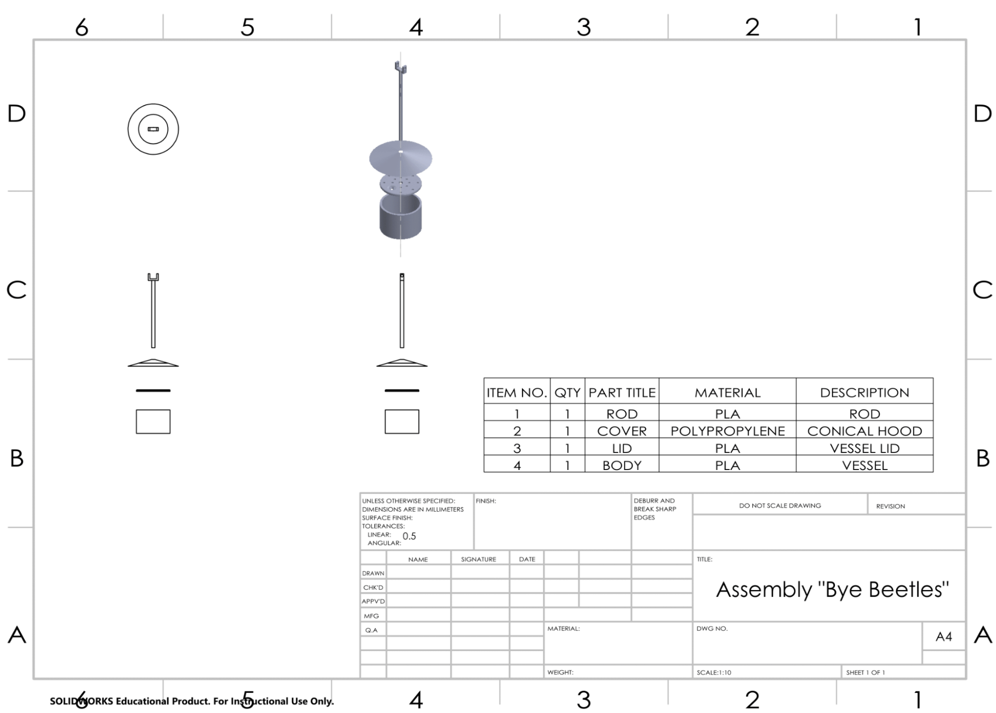


Figure 8.4. Drawing of Vessel Body

Assembly Drawing



ITEM NO.	QTY	PART TITLE	MATERIAL	DESCRIPTION
1	1	ROD	PLA	ROD
2	1	COVER	POLYPROPYLENE	CONICAL HOOD
3	1	LID	PLA	VESSEL LID
4	1	BODY	PLA	VESSEL

Figure 9. All Parts Fitted Together (Exploded View)

All our drawings are catered for printing tolerances, not specifically geared for machining, as our client does not have access to a machine shop and preferred having the design be printed. Vessel Body, Vessel Lid and the rod are 3-D printed while the conical cover drawing shows making of the part through using a dimension-cut on a regular sheet of plastic and super glue. All 3-D printings are advised to be done on large flat surfaces of the parts. The tolerances are subject to changes according to the specifications with the 3-D printer of our client although our parts are designed to fit easily with specifications of most 3-D printed on the market. And the hand-crafting piece is tolerated so that it is easily recreatable. One each of all parts are designed through the sequence of Rod, Conical Cover, Vessel Lid, Vessel Body as shown in the assembly drawing for our design, "Bye Beetles".

Bill of Materials & Estimated Cost of Final Deliverable

Material	**Quantity**	**Method of Acquisition**	**Estimated unit cost**	**Estimated cost**	
Peppermint oil	1	Purchased	$6.67	$6.67	
Reed diffuser wicks	2	Purchased	$10.00	$20.00	
Mounting Putty	1	Purchased	$2.29	$2.29	
Translucent file folders	1	Purchased	$5.49	$5.49	
Hard plastic sheet	1	Purchased	$14.98	$14.98	
Super glue	1	Purchased	$4.49	$4.49	
3D printer filament	1 (roll)	Scavenged	$22.99	$22.99	
Fishing line	1 (roll)	Scavenged	$2.37	$2.37	Total cost: $52.62

Figure 10: Bill of Materials & Estimated Cost of Final Deliverable

More detailed information: Budget Spreadsheet

For one device, it cost a total of $52.62 to build all the parts. However, because some materials, such as the 3D printer filament, translucent file folder, superglue, and fishing line, only required the use of a portion of it, the same one could be reused to manufacture more devices without purchasing another one. Furthermore, we were only able to find reed diffuser wicks that came with essential oil scents at the stores we went to, which made them more expensive than if we bought the wicks by themselves.

Process Router

Body

Drawing 1/4

Process	Machine/Tool	Notes
3D Print Body	3D Printer	Keep an eye on the first layer. If the first layer is off, stop the process, remove the failed print, and print again. Once the print is complete, check the part for any defects.

Lid

Drawing 2/4

Process	Machine/Tool	Notes
3D Print Body	3D Printer	Same as above.

Rod

Drawing 3/4

Process	Machine/Tool	Notes
3D Print Body	3D Printer	Same as above.
Create loop of string through top of rod	By hand, fishing line	Thread a two feet piece of fishing line through the holes in the rod and tie a knot.

Cone Cover

Drawing 4/4

Process	Machine/Tool	Notes
Draw outline	Compass/Protractor	Use the protractor for the 13.04 degree sector in the larger circle. Make sure measurements are in millimeters.
Cut out cone cover	Scissors	It is best to cut less on the outer radius rather than more, as less cut off equates to more coverage from rain.
Bend cone cover	Electrical tape	Place rod through center of cone cover. Bring the circle together by overlapping the plastic over the cut sector, and once the inner circle is snugly fit around the rod, bend the cover to make the cone shape. Secure with electrical tape.

Assembly

Process	Machine/Tool	Notes
Attach cone cover to rod	By hand, mounting putty	Secure with mounting putty on the top and bottom.
Glue rod to body	By hand, superglue	Make sure that the lid has the rod placed through it before gluing the rod.
Cut reed diffusers to length	Scissors	Measure the length needed. The maximum length is from the bottom of the body to the bottom of the cone cover.

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